Experimental Analysis of Heat Transfer Rate in Corrugated Plate Heat Exchanger Using Nanofluid in Milk Pastuerization Process

K.Tamilselvan, B.Sivabalan, R.Prakash, M.Manojprasath, A.Mahabubadsha

Abstract— **Plate heat exchanger is one of the thermal energy transferring devices, which transfer the heat between different fluids. This is widely used in different applications because of its compact in size and higher efficiency compared to other types of heat exchangers. In this research work we are analyzing the performance of corrugated type plate heat exchanger using nano fluid in milk pasteurization process. In this work the Al2O3 nano particle is used to prepare nanofluid and the base fluid used as demineralized water. The main advantage of using PHE in this work is that it has high heat transfer area. The main focus of using nanofluid is that it has high thermal conductivity than base fluid like water, ethylene glycol, etc. The concentration of nanofluid is 0.3 % of its volume concentration. Here the milk is used as hot fluid and the nanofluid is used as cold fluid. The heat transfer rate is increased with increasing the concentration nanofluid, size of particle and type of materials used. From this work we expected that the enhancement high heat transfer rate. To get efficient heat transfer rate counter flow arrangements are made in this work.**

Index Terms— **gasketed PHE; AL2O3 nanofluid as coolant; heat transfer coefficient comparison**

I. INTRODUCTION OF PLATE HEAT EXCHANGER

Plate heat exchangers (PHEs) were introduced in the 1930s and were almost exclusively used as liquid/liquid heat exchangers in the food industries because of their ease of cleaning. Over the years, the development of the PHE has generally continued towards larger capacity, as well as higher working temperature and pressure. Recently, a gasket sealing was replaced by a brazed material, and each thermal plate was formed with a series of corrugations (herringbone). These greatly increased the pressure and the temperature capabilities.

The plate heat exchanger normally consists of corrugated plates assembled into a frame. The hot fluid flows in one direction in alternating chambers while the cold fluid flows in true counter-current flow in the other alternating chambers. The fluids are directed into their proper chambers either by a suitable gasket or a weld depending on the type of exchanger chosen. Traditionally, plate and frame exchangers have been used almost exclusively for liquid to liquid heat transfer. The best example is in the dairy industry.

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Today, many variations of the plate technology have proven useful in applications where a phase change occurs as well. This includes condensing duties as well as vaporization duties. Plate heat exchangers are best known for having overall heat transfer coefficients (U-values) in excess of 3–5 times the U-value in a shell and tube designed for the same service. Plate heat exchanger is an attractive option when more expensive materials of construction can be employed. The significantly higher U-value results in far less area for a given application. The higher U-values are obtained by inducing turbulence between the plate surfaces. Owing to this they are also known to minimize the fouling.

The corrugated pattern on the thermal plate induces a highly turbulent fluid flow. The high turbulence in the PHE leads to an enhanced heat transfer, to a low fouling rate, and to a reduced heat transfer area. Therefore, PHEs can be used as alternatives to shell-and-tube heat exchangers. R410A approximates an azeotropic behavior since it can be regarded as a pure substance because of the negligible temperature gliding.

The heat transfer and the pressure drop characteristics in PHEs are related to the hydraulic diameter, the increased heat transfer area, the number of the flow channels, and the profile of the corrugation waviness, such as the inclination angle, the corrugation amplitude, and the corrugation wavelength.

The method of enhancement of heat transfer rate operationally is broadly divided as (1) active methods and (2) passive methods. Active method includes electro hydrodynamics, jets, sprays, ultrasound waves, synthetic jet heat transfer and high amplitude vibratory motion, while passive method include surface coating, nanoscale coating, nanofluid, hydrodynamic cavitations, turbulence promoters and mixing promoters . Among them, three methods are considered as effective methods to enhance the heat transfer which are (1) utilizing nanofluids, (2) inserting fluid tabulators and (3) roughing the heat exchanger surface. A nanofluid is a mixture of nano sized particles and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. The nanofluid exhibits different thermo physical properties than the base fluid. Generally thermal conductivity of nanofluids is higher than the base fluid which increases the heat transfer rate. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid.

II. RELEVANCE OF NANOFLUIDS

Convective heat transfer coefficient is utmost important parameter that attracts many researchers to investigate the heat transfer augmentation in nanofluids,

relevant to numerous engineering applications such as- nuclear systems cooling, chemical process and microelectronics. Owing to improved heat transport properties, nanofluids are believed to be relatively potential fluids that attribute to enhance heat transfer coefficients. However, the additions of nanoparticles merely in the base fluids not impinge on the thermal conductivity but also the viscosity and the specific heat capacity. A few review papers have been discussed on the application of nanofluids in heat exchangers. In present study, we try to particularly review the application of various nanofluids in plate heat exchanger, in more details. However, probably no comprehensive literature available on application of nanofluids particularly in plate heat exchanger much. Moreover, the purpose of this paper is to explain the application of nanofluids in plate heat exchangers based on experimental investigations.

2.1. Preparation of nano fluids

Nanofluids were prepared by two step method in this research work. The concentration is prepared by using magnetic stirrer and ultrasonic bath. First placed the water in a beaker and put the measured amount of nanoparticles in a beaker. Magnetic sterification was allowed for about an hour and then place the beaker in the sonicator bath and sonication process was run for 4-5 hours. At one time only two beakers were placed in a sonicator so that the water level in the sonicator bath did not exceed the upper limit. The techniques used for stabilization and homogenization are mentioned in literature. Small amount of CTAB (Cetyl trimethyammonium bromide) was added to achieve good suspension of nanoparticles. Efforts were made to homogenize the suspension, so that it remained in a stable condition for a long period.

III. EXPERIMENTAL SETUP

A. Plate heat exchangers:

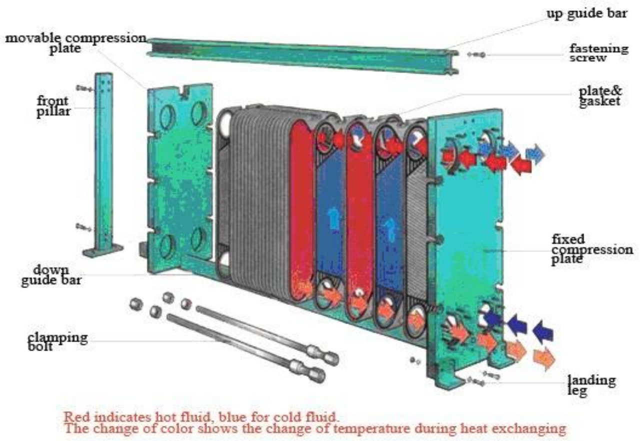

Figure.1

The plate heat exchanger is formed up by a set of corrugated metal plates. The corrugated plates are mounted in a frame with a fixed plate on one side and a movable pressure plate and pressed together with tightening bolts. The corrugated plates serve not only to raise the level of turbulence, but also provide numerous supporting points to withstand the pressure difference between the media.

The hot medium may not flow through the apparatus without the cold medium flowing through. This is to prevent damage to the apparatus. In case the cold medium is present but does not flow while the hot medium is flowing through, the cold medium will start boiling and the apparatus will be damaged. Sudden pressure and temperature changes should be prevented. When a heat exchanger (filled with water or a water mixture) which is not in operation is exposed to temperatures below zero, the plates can become deformed. If a danger of frost occurs, the heat exchanger should be drained completely.

B. *Parts of plate heat exchangers*

- ❖ Frames
- ❖ Plates
- ❖ Gaskets
- ❖ Flow Arrangements

C. Apparatus

The setup employed for this experiment is as follows.

1. A stainless steel plate heat exchanger with a facility to measure inlet and outlet temperature of hot and cold fluid with an accuracy of 0.1˚ C.
2. The plates are corrugated, There are a total of 5 plates making 4 chambers for the fluid transport–two for the cold fluid and two for the hot fluid.The total heat transfer area available is equal to that of the number of plates
3. The cold fluid used here is ALUMINIUM OXIDE nanofluid and the hot fluid is milk.
4. A stainless steel insulated tank with a heater to act as a reservoir for the hot fluid.
5. Hot fluid circulation pump is used as 1HP power output and which is have head displacement upto 20m.
6. Cold fluid inlet from the pump which is having 28W output and which having head displacement upto 5m.
7. Four temperature sensors at the inlet and outlet points for each of the two fluids. The hot-fluid inlet wired thermocouple is also a thermostat control, which controls the heater connected to the reservoir by a simple relay mechanism.
8. Rotameters for fluid flow measurements.

D. Schematic diagram of experimental setup

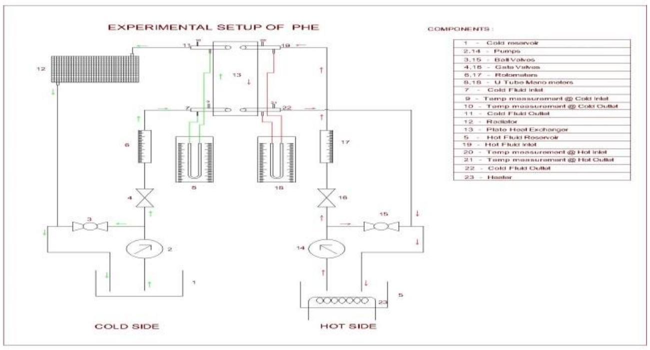

Figure 2. experimental layout of PHE

E. Selection of material

Plate Type : VT04 PH K
Heat Transfer Area (Total/per unit) : 0.232 m^2
Number of Plates (Total/per unit) : 7
Plate Thickness : 0.60 mm
LMTD : 35.99 K
Plate Material : SS 316
Gasket Material/ Gasket Type

: NBR / Glued
Internal flow (passes × channels): 2×6
No. of Frames : 1
Frame Material : CS-IS 2062 Gr B
Surface : Painted FPC 12001

IV. EXPERIMENTAL OBSERVATION AND CALCULATION

A. Observation

1) aim:

To determine the overall coefficient of the counter flow plate heat exchanger.

2) factors influences:

Over all heat transfer coefficient depends on

- Hot fluid temperature
- Cold fluid temperature
- Flow rate
- Properties of fluid

3) apparatus required:

- Plate heat exchanger
- Stop watch
- Volumetric flask or Measuring Jar
- Rotometer

4) Properties of Al2o3 nanoparticle:

- Size = 50nm
- Specific surface =15 – 20 m^2/g
- Density = 3890 kg/m^3
- Thermal conductivity = 30 w/m-k
- Specific heat capacity = 880 j/kg-k
- Properties of base fluid (water):
- Density = 996 kg/m^3
- Thermal conductivity = 0.6065 w/m-k
- Specific heat capacity = 4180 j/kg-k
- Viscosity = $7.9779*10^{-4}$ kg/m-s

Properties of nanofluid:

- Density = 1016.352 kg/m^3
- Thermal conductivity = 1.0085 w/m-k
- Specific heat capacity = 4170.1 j/kg-k
- Viscosity = $8.0377*10^{-4}$ kg/m-s

B. formula used

Calculation steps for nano fluid:

- Concentration of nano fluid:

$$\emptyset = \frac{\left\{\begin{matrix}\text{Volume of}\\ \text{Nanoparticle}\end{matrix}\right\}}{\left\{\begin{matrix}\text{Volume of Nanoparticle}\\ +\text{Volume of water}\end{matrix}\right\}} \times 100$$

$$\emptyset = \frac{\frac{W_{nanoparticle}}{\rho_{nanoparticle}}}{\frac{W_{nanoparticle}}{\rho_{nanoparticle}} + \frac{W_{water}}{\rho_{water}}} \times 100$$

- Density of nanofluid:

$$\rho_{nanofluid} = \{\emptyset \times \rho_{nanoparticle}\} + \{(1-\emptyset)\rho_{water}\}$$

Where,

ρ_{nf}– density of nanofluid
ρ_f - density of base fluid
ρ_p - density of nanoparticle
ϕ - volume concentration

- Specific heat capacity of nanofluid:

$$C_{p,nanofluid} = \frac{\left[\begin{matrix}\emptyset \times \{\rho_{nanoparticle} \times C_{p,nanoparticle}\}\\ +(1-\emptyset) \times \{\rho_{water} \times C_{p,water}\}\end{matrix}\right]}{\rho_{nanofluid}}$$

Where,

C_{pnf} -heat capacity of nano fluid
C_{pf} – heat capacity of base fluid
C_{pp} – heat capacity of nanoparticle

- Viscosity of nanofluid:

$$\mu_{nanofluid} = \{1 + (7.3 \times \emptyset) + (123 \times \emptyset^2)\}\mu_{water}$$

Where,

μ_{nf} –viscosity of nanofluid
μ_f – viscosity of base fluid

- Thermal conductivity of nanofluid:

$$k_{nanofluid} = \frac{\left[\begin{matrix}\{k_{nanoparticle}\} + \{2 \times k_{water}\}\\ +\{2 \times (k_{nanoparticle} - k_{water}) \times \emptyset\}\end{matrix}\right]}{\left[\begin{matrix}\{k_{nanoparticle}\} + \{2 \times k_{water}\}\\ -\{(k_{nanoparticle} - k_{water}) \times \emptyset\}\end{matrix}\right]}$$

Where,

K_{nf} -thermal conductivity of nanofluid
K_f – thermal conductivity of base fluid
K_p –thermal conductivity of nanoparticle

- For hot fluid

Nusselt Number $Nu= 0.023Re^{0.8} Pr^{0.4}$
Over all heat transfer co-efficient $U= [1/h_i+1/h_o]^{-1}$
Heat Transfer Rate $Q = UA\,\Delta T_m$

- For cold fluid

Density of nano fluid $\rho nf=(1-\phi)\, \rho f + \phi \rho p$ 1
Cpnf is the nanofluid heat capacity Cpnf = (1- ϕ) Cpf + ϕ Cpp 2
Q is the rate of heat transfer Q = mCp (T1-T2)

V. RESULTS AND DISCUSSION

To evaluate the accuracy of measurements experimental system has been tested with demineralised water before measuring the heat transfer characteristics of nanofluid at a

volume concentration of 0.3 %.from the experimental system, the values that has been measured are, the temperatures of the inlet and outlet of both hot and cold fluid at different mass flow rate. The final result of this research shows that the heat transfer rate is increased in nanofluid compared to water at different mass flow rate.

VI. CONCULSION

This research work is focused on the heat transfer analysis of corrugated plate heat exchanger using nanofluid in milk pasteurization process. The heat transfer performance of corrugated plate heat exchanger using Al_2O_3 nanofluid has been experimentally analyzed. By our analysis, on using 0.3% concentration of nanoparticles in the nanofluid it yields a result of about 46% increase in heat transfer rate compared to using cold water as a coolant. By using corrugated structure in heat transfer plates fouling will be reduced considerably. This research work can be further extended for heat transfer analysis and fouling reduction using nanoparticle coating on the plates of a heat exchanger.

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